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A PERFORMANCE EVALUATION OF MINI-LASER CARTRIDGE DEVICES.(U)
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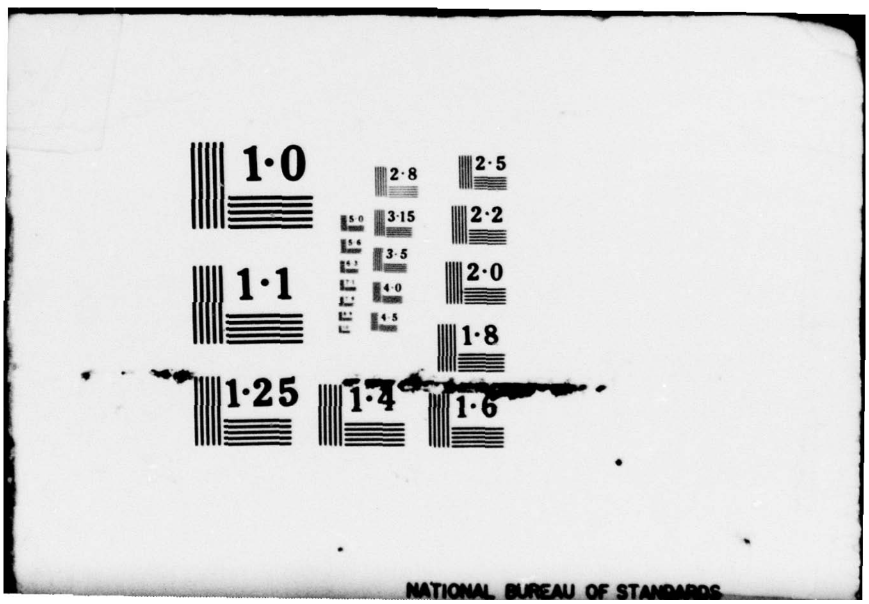
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RESEARCH AND DEVELOPMENT TECHNICAL REPORT

DELNV-TR-79-1

A PERFORMANCE EVALUATION OF MINI-LASER CARTRIDGE DEVICES

J. W. Strozyk
L. Wacenske

NIGHT VISION & ELECTRO-OPTICS LABORATORY
Laser Division

May 1979

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18. SUPPLEMENTARY NOTES

The work described herein is an adjunct effort to Contract DAAB07-76-C-0856

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The development of miniaturized laser rangefinders and laser sighting systems has evolved as a direct result of large scale integration of electronics and more recently, the integration of the laser transmitter assembly into a "cartridge" device. This paper addresses the evaluation of the latest "bonded cartridge" device design, presents performance data and provides a comparitive assessment with previous devices. Laser performance is discussed in terms of corrected beam divergence, beam quality and beam

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stability as well as energy efficiency. Although the number of devices available for examination was small (6), the improvement in beam characteristics over previous designs was readily observed.

PREFACE

The work described herein is an adjunct effort to Contract Number DAAB07-76-C-0856 and was performed in the Laser Division, Night Vision and Electro-Optics Laboratory, Fort Monmouth, NJ. At the time, L. Wacenske was a member of the Cadet Corp of the US Army Military Academy, West Point, NY on temporary duty to Fort Monmouth and J. W. Strozyk was a Project Engineer in the Laser Division. This effort was conducted under the One/Two Micron Laser Technology subtask. R. Wright and J. Yee of the Laser Division contributed to the work in supplying measuring equipment and discussing previous efforts. Additional discussions with A. C. Safyurtlu, formerly of United Technologies Corporation, Norden Division concerning design parameters are appreciated.

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FIGURES

TABLES

1. INTRODUCTION AND BACKGROUND

The development of miniaturized laser rangefinders and laser sighting systems has evolved as a direct result of large scale integration of electronics and more recently, the integration of the laser transmitter assembly.[1-3] The concept of an integrated, "cartridge," laser assembly, while obviously related to reduced performance requirements of short range direct, as well as indirect fire systems, could only be realized through successful application of state of the art technology. Conceptually, the cartridge laser requires a laser rod, a passive "Q" switch and appropriate dielectric reflectors, bonded together as an integral, non-adjustable unit. A suitable excitation or pump source, and a pumping cavity would complete the laser transmitter assembly. Laser cartridges of this type have been designed and fabricated[3-5] using Nd:YAG laser rods, organic nickel complex dye in a polymethylmethacrylate (PMMA) host, and dielectric reflectors. The passive "Q" switch is epoxy bonded to the laser rod and to a 1.06 maximum reflectance mirror. Output coupling for the laser energy is achieved through a suitable dielectric reflector deposited on the opposite end of the laser rod. Bonded cartridges were initially configured as "stable resonators" with flat/flat as well as flat/concave reflectors. These units served to validate the cartridge concept but were subject to performance variations with respect to beam divergence, beam wander, efficiency and output energy stability, all of which are associated with multimode operation.[3] Most recently bonded laser cartridges utilizing "Hybrid Unstable Resonator (HUR)" designs have been developed to provide improvements in performance. This report describes and presents both active and passive evaluations of HUR cartridge lasers designed to meet certain performance goals under ECOM Contract DAAB07-76-C-0856, "Unstable Resonator Laser Cartridge Development." Figure 1 illustrates the three resonator configurations described, while Table 1 lists the performance goals and Table 2 the pertinent design parameters of the six HUR cartridges being considered here.

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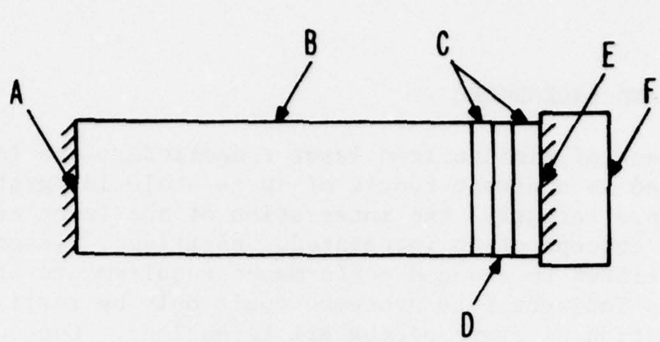
1. F. Kobylarz, et al., "Mini Laser Rangefinder," 6th DOD Laser Conference, Colorado Springs, CO., U.S.A.F. Academy, August 1974.

2. F. Kobylarz, et al., "Laser Rangefinder Sight AN/PVQ-3," 7th DOD Conference on Laser Technology, US Military Academy, West Point, NY, June 1976.

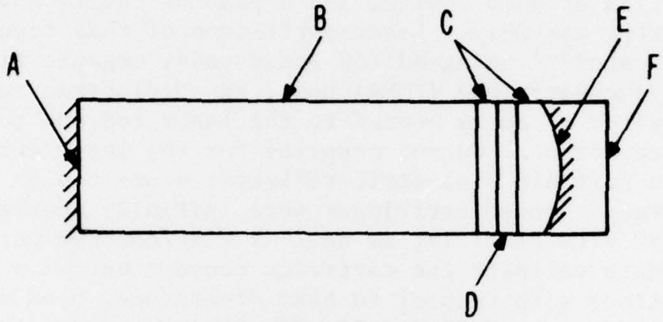
3. R. Wisnieff, et al., "Laser Cartridge Development," 7th DOD Conference on Laser Technology, US Military Academy, West Point, NY, June 1976.

4. R. Wisnieff and D. Longo, "Laser Cartridge Concept Development Study," ECOM-74-0376-F, April 1976.

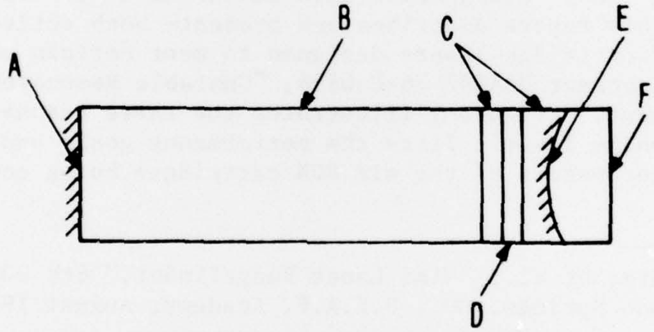
5. A. C. Safyurtly, "Unstable Resonator Laser Cartridge Development Study," ECOM-76-C-0856, October 1977.



FLAT/FLAT STABLE



FLAT/CONCAVE STABLE



FLAT/CONVEX HYBRED UNSTABLE

A: OUTPUT COUPLER, DIELECTRIC REFLECTOR.

B: 3 x 15 mm Nd:YAG, LASER ROD.

C: EPOXY BONDS (TECH KIT E-7).

D: DYE "Q" SWITCH DISC, PMMA.

E: MAXIUM REFLECTIVITY DIELECTRIC REFLECTOR (1.0 MICRON).

F: BK7 GLASS SUBSTRATE.

FIGURE 1. RESONATOR CONFIGURATIONS

TABLE 1. DESIGN GOALS.

ENERGY OUTPUT:	2.0 MILLIJOULES/PULSE
BEAM DIVERGENCE (CORRECTED):	2.0 MILLIRADIANS
ENERGY INPUT:	2.0 JOULES MAXIMUM
REPETITION RATE:	3.0 PULSES PER MINUTE
LIFETIME OF CARTRIDGE:	10,000 SHOTS MINIMUM

TABLE 2. HUR CARTRIDGE PARAMETERS.

HUR NUMBER	RESONATOR LENGTH (MM)	REFLECTOR RADIUS (M)	RESONATOR MAGNIFICATION	"Q" SWITCH DYE DENSITY (U GRS.)	SINGLE PASS TRANSMISSION OF "Q" SWITCH* (INITIAL/FINAL %)	OUTPUT COUPLER REFLECTIVITY (%)
7	17	3.0	1.16	28	64/90	67
8	17	4.0	1.14	32	61/89	67
9	17	4.0	1.14	24	69/91	54
10	17	4.0	1.14	32	61/89	67
11	17	4.0	1.14	28	64/90	67
12	17	3.0	1.16	28	64/90	67

*INITIAL TRANSMISSION - UNSATURATED

FINAL TRANSMISSION - SATURATED

2. PASSIVE TESTING

Prior to performing any active laser testing each cartridge was subjected to passive evaluations to determine the Nd dopant level of the laser rods and to qualitatively assess the degree of resonator alignment.

Neodymium concentrations are routinely measured on most laser rods to preclude unexplained laser performance variations in comparative testing of identically doped material. The test applied requires measurement of the fluorescent lifetime of the Nd ion after narrow band excitation with an injection laser emitting at 0.8 microns. The respective lifetimes of each cartridge measured, with its associated Nd concentration in atomic percent is presented in Table 3. Although the concentrations are higher than typically encountered (1.0-1.2 At%) in Nd:YAG devices, they are within the recommended range for mini-laser type operation.[6] Variations in concentration from rod to rod are within the usual range for Nd:YAG manufacturers.

Since the cartridge concept precludes adjustment of the resonator once it is assembled, each unit was examined in a standard Fizeau type interferometer. A well collimated, spacially filtered HeNe laser was used as the source. The resulting interference pattern was expanded, viewed and photographed using a CCTV system. This test provides qualitative information, in this case, related to the alignment of the spherical, internal, maximum reflector and the various other surfaces. Resulting photographs of the fringe patterns for units 8 through 12 are included in Table 3. HUR 7 was not photographed but was noted to have a pattern similar to HUR 9.

If one considers the cartridge resonator as having two dominant reflecting surfaces, one flat the other spherical, the fringe pattern should consist of a central bright spot with concentric circular fringes about it, provided the surfaces are parallel or not optically inclined to one another. When this condition is not fulfilled (inclination exists), the resulting fringes appear circular but displaced toward that area which is optically thinner. Examination of the photographs and applying this interpretation leads one to conclude that alignment quality proceeding from best to worst is: HUR 12, 8, 10, 9. The fringe system of HUR 11 does not appear as a simple case of the above and may be two systems superimposed, a flat-flat with a flat-spherical. This possible interpretation arises from the apparent central bright region and the two fairly straight thick fringes adjacent to it. During the course of this examination, a prefunctory check of fringe change with temperature using alcohol evaporation was accomplished. The effect of cooling the rear mirror Q-switch junction was quite noticeable while that of cooling the rod was insignificant. Similar effects of lesser magnitude were observed using heat to elevate the temperature of the junction.

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6. J. W. Strozyk, to be published.

TABLE 3. PASSIVE HUR DATA.

HUR NUMBER	INTERFEROMETER PATTERN	FLUORESCENT LIFETIME (μSEC)	NEODYMIUM CONCENTRATION (ATOMIC %)
7		193	1.6
8		188	1.66
9		NOT MEASURED	----
10		199	1.53
11		198	1.53
12		191	1.64

Observations of the interference fringes during laser pumping demonstrated that large and rapid changes occur during and immediately after pumping. It is felt that these changes are induced by temperature gradients in the junction, either from direct pumping, conductive heat transfer from the cavity or radiative-conductive transfer from the pump lamp electrode area which is in near contact with this portion of the cartridge. A possible relationship between these observations and certain laser performance, as will be described, most likely exists but was not critically studied.

3. LASER TESTING

Active tests were limited to measurements of specific parameters pertinent to successful inclusion of the HUR cartridges in Mini-Laser Rangefinders or Laser Sights. These include: threshold energy for a single pulse, corrected beam divergence (energy in the bucket), observation of spacial beam quality and position, and double pulse threshold if single pulse threshold was less than 2 joules. Data were collected to determine if the original design goals were being met and to ascertain whether the HUR alignment procedures were successful.

The laser pumping cavity was the same as used on previous cartridge tests and consisted of a solid PMMA pumping cavity with the outer wall spray coated with barium sulphate. The solid cavity serves to hold both the lamp and cartridge in holes drilled to accept each. The barium sulphate coating provides a diffuse reflecting surface to assist in achieving a more uniform pumping condition. An EG&G xenon gas lamp, FX-135-0.6, with a PFN having C = 11 microfarads, L = 55 microhenries was used to pump the laser rod. The resulting pumping pulse width is approximately 65 microseconds at the half-intensity points. This lamp survived the entire test sequence and an excess of 10,000 shots were accumulated on it without serious degradation in operation. At the conclusion of the test series the lamp wall was slightly "crazed" and exhibited some discoloration.

Laser energy output was measured through a variable aperture located at the focal plane of an uncoated 1.0 meter focal length lens. The minimum aperture setting corresponded to approximately a 2 milliradian beam divergence while the maximum opening was on the order of 44 milliradians. The same EG&G Radiometer used throughout the cartridge program was used to measure the pulse energy as well as determine the number of pulses present. Beam quality and wander were evaluated using a CCTV system with appropriate filters.

Laser cartridge units with stable resonators are known to have multimode output which leads to large beam divergence and non-uniform intensity distributions ("hot-spots"). Additionally, through suspected interaction with the saturable absorber, lower single pulse laser efficiency and a tendency to multi-pulse, have been attributed to the presence of these higher order modes.[3] The HUR design was implemented to increase the lowest order mode volume thereby decreasing the described higher order mode deficiencies. Further, the lowest order mode of an unstable resonator should have a uniform amplitude distribution and an output phase front curvature amenable to correction with a simple lens or lens system, providing a minimized far-field

divergence. Considering these factors, only corrected beam parameters were examined and recorded using a small adjustable telescope for correcting. This system was adjusted for each cartridge to yield the minimum spot size in the plane of the aperture. A back focal length of 15 to 17 centimeters was found to yield the best wavefront correction. These measurements, coupled with observations of beam quality, are appropriate to an evaluation of these units for application in rangefinder devices.

4. LASER DATA AND OBSERVATIONS

Although six HUR cartridges were fabricated for testing, only four (HUR 8, 10, 11 and 12) were fully tested. HUR 7 was damaged during the testing and HUR 9 would not fit physically into the pumping cavity due to the close proximity of the lamp. Data plots of energy output, normalized to full aperture values versus receiving aperture radius, have been prepared for these cartridges and are presented in Figure 2. Pertinent numerical data describing threshold energy, double pulse threshold, percentage of energy output in 2 milliradians (corrected) and efficiencies, have been tabulated in Table 4.

Cartridges 8, 11, and 12 could not be pumped at 2.0 joules input due to double pulse operation. However, in monitoring the energy output for cartridges 8 and 12, while increasing the input towards 2.0 joules, it was determined that no significant additional energy was being extracted at the higher inputs until double pulse threshold is reached. This conforms to this type of "Q" switch operation.[7]

All of the units tested exhibited a relatively high sensitivity to the rate at which data was taken as well as to the total number of data shots in a series. Thus, each cartridge was pumped at a rate which allowed the initial data points to be repeated. In general, rates of 2 pulses per minute to 1 pulse per 2 minutes were possible. The apparent effect of operating at too high a pumping rate as well as a long data series was to lower the single pulse laser threshold temporarily. HUR 12 was found to be least sensitive to this, while HUR 11, which yielded the highest full aperture efficiency, demonstrated a further anomaly in that the beam "broke up" as the rate increased. Examination of this effect using the CCTV system, while monitoring the energy through the 2 milliradian aperture, verified that the beam was dividing about the axis of observation. When HUR 11 was pumped at 1 pulse per 2 minutes, a highly symmetric output was obtained. As the rate was increased, the beam (spot) divided into two lobes which separated about the axis until no energy was passing through the aperture. Also, it was noted that at the 1 pulse per 2 minutes rate, similar splitting was observed after 10 or more shots. By observing the direction of the beam splitting and relating it to the passive interferometric examination, it was determined that the separation was occurring along a parallel direction to a normal connecting the two large fringes. Thus, this splitting may be a diffraction effect due to some unobservable defect in the cartridge bond or indeed a change from predominantly lowest order mode operation to highest order. The remaining cartridges exhibited only minor

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7. J. W. Strozyk, J. Moss, Jr. and J. Hynd, "Lightweight Small Laser Transmitter Design for Rangefinders," US Army Science Conference, West Point, NY, June 1972.

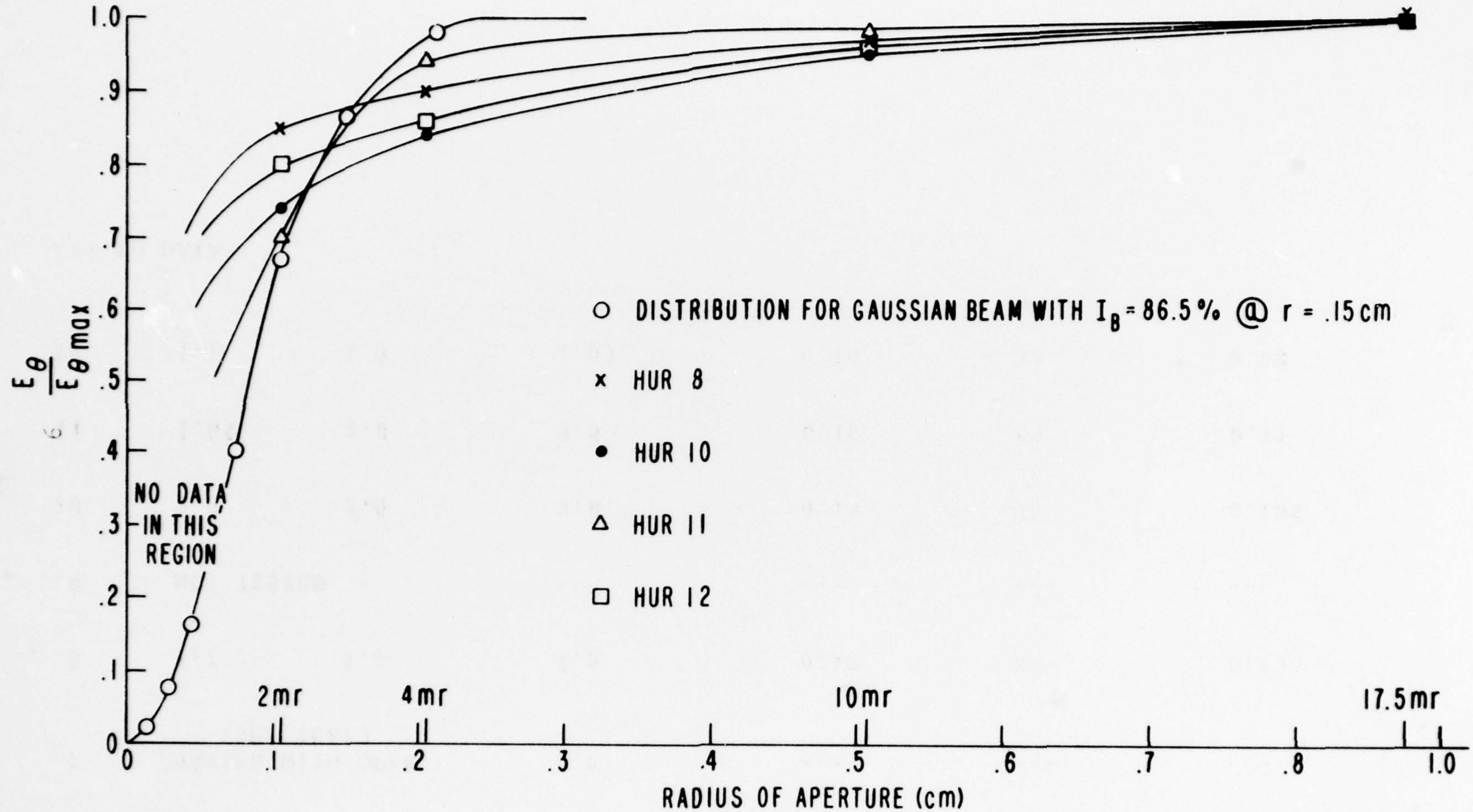

Figure 2. Normalized energy output as a function of beam divergence.

TABLE 4. HUR LASER PERFORMANCE.

HUR NUMBER	THRESHOLD ENERGY S/PULSE (JOULES)	THRESHOLD ENERGY D/PULSE (JOULES)	ENERGY OUT FULL APERTURE (MJ)	FULL APERTURE EFFICIENCY (%)	ENERGY OUT 2 MRAD (%)	2 MRAD EFFICIENCY (%)
7	VARIED WITH OPER. (SEE TEXT)		0.6	---	---	---
8	1.7	2.0	2.0	0.12	84	0.10
9	NOT TESTED		---	---	---	---
10	2.0	2.0	2.8	0.14	74	0.105
11	1.65	2.0	2.6	0.16	69	0.11
12	1.7	1.9	1.63	0.10	80	0.08

--- NO DATA

beam changes relating to the repetition rate or number of pulses. In each case though, the general trend was toward a sharper, more defined spot. These effects are apparently related to thermal processes, either directly due to pumping or possibly heating of the PMMA pump cavity. From the data plot in Figure 2 for HUR 11, it should be noted that when pumped appropriately more than 95% of the output energy is contained within a corrected 4 milliradian beam divergence. This is to be compared with 80-90% for the others.

During testing of HUR 7 it was found that measurements could not be repeated at any reasonable rate of pumping. Although the energy output, full aperture, remained steady at 0.6 millijoules for single pulsed outputs, the input threshold energy reduced roughly with each pulse. In examining this effect, the cartridge was subjected to a rapid fire (3 pulses per minute) sequence with a resulting change in threshold energy from approximately 1.6 to 1.3 joules. After several hundred shots it was noted that the output energy dropped from 0.6 millijoules to 0.3 millijoules at which time the test was halted. Upon removal of the cartridge from the pump cavity for study under a microscope, the rod physically separated from the Q-switch element. The epoxy bond at this junction had failed and examination showed that the bond from the PMMA to the dielectric reflector separated over a large area. It would appear that the rod to PMMA bond started failing near the rod axis while the bond at the PMMA-dielectric started at the outer edge. When the drop in output energy occurred, a temperature probe located adjacent to the pump cavity registered an air temperature of 70°C. The initial air temperature was 28°C during this sequence. Considering the high temperature, this failure in no way detracts from the design since the operating temperature greatly exceeded all anticipated conditions.

Upon completion of all laser testing, the cartridges were inspected for damage using a microscope. No notable damage of the "Q" switch element was observable, however various defects or flaws were present in the vicinity of this element, either in the epoxy bonds or the PMMA itself. HUR 10 and 11 appear to contain small scattering sites which tend to cluster together. Unit 11 is by far the worst. The sites appear as bright spots under white light illumination and could be gas bubble voids or impurities in the epoxy. HUR 8 has 3 small flaws of this type while 12 appears to be free of this type of defect. HUR 12 does have a small sleck or scratch in the region of the "Q" switch. Inasmuch as no pre-lasing examination was performed at ERADCOM and each cartridge was lased prior to delivery, it cannot be accurately determined whether these flaws were created as a result of laser operation. It is felt that they are most likely not laser induced, since other cartridges which were purposely damaged exhibited blackened regions. There were no areas of bond separation observed in the remaining cartridges 8 through 12.

5. DISCUSSION

Outwardly, examination of the performance in Table 4 and the goals of Table 1 lead one to conclude that one HUR cartridge met or exceeded the design goals. Upon allowing for energy losses in the optical system used for the measurements (estimated at 10-15%), units 8, 10 and 11 exceed or are within experimental error of yielding the desired output. HUR 12 is

within 25% of the energy output in 2 milliradians and has the lowest value of the series. More significant, however, is the relative improvement in performance of these assemblies over previously tested units of the stable resonator type, and initial HUR designs.

During the early efforts to devise a unitized laser cartridge, the flat/flat or flat/concave resonator design yielded few units with greater than 1.5 millijoule output energy.[3] This energy was contained within a full beam of 12-15 milliradians typically, and was subject to beam wander, break-up and hot spots as well as multiple pulsing. These problems severely limited the potential applications of the concept with respect to military equipments.

In the initial phases of development of the HUR design, various units were tested to the same goals.[8] These assemblies, while yielding threshold energies below 2.0 joules, exhibited output energies well below 2.0 millijoules full beam. Full beam efficiencies ranging from 0.02% to 0.2% were obtained with output energy in a 2 milliradian beam being less than 1.0 millijoule. Efficiency, for the energy output in 2 milliradians, varied from 0.01% to 0.05%. Collimating efficiencies from 35% to 65% of the full beam converted to 2 milliradians were prevalent. Repeatability and consistency from unit to unit were poor. The present units, in comparison, have demonstrated greater consistency with respect to all parameters. Threshold energies are between 1.65 and 2.0 joules. Full beam efficiencies are from 0.1% to 0.16%, while the efficiency for output in 2 milliradians varies from 0.08% to 0.11%. Collimation efficiencies obtained are higher than previously attainable (approximately 70% or more) and beam stability is excellent.

6. CONCLUSIONS

The adoption and development of the Hybrid Unstable Resonator structure has accomplished its fundamental purpose of improving pulse to pulse stability and increasing the collimation efficiency with no noticeable hot spots. This has been achieved at no increase in threshold energy and indeed has widened the "window" between single and double pulse laser threshold. Although the limited number of units tested does not provide sufficient statistical data to determine which specific parameter change would improve the energy efficiency, it seems plausible to expect little if any impact on the correctable divergence values for the HUR structure for minor design changes. Obviously dye density, output coupling, mirror radii and refinement of the assembly process could lead to an energy output increase. Since these units were designed for 1.0 AT% Nd dopant concentrations and the laser rods had 50% greater dopant present, the parameters were not optimum for efficiency. Prior to inclusion of this HUR cartridge laser device in military equipments, optimization as well as examination of the thermal observations must be performed.

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8. R. Wright, Private Communication.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	metric tons	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	L
pt	pints	0.47	liters	L
qt	quarts	0.95	liters	L
gal	gallons	3.8	liters	L
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* 1 in = 2.54 cm (exactly).

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10 000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	metric tons (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
L	liters	2.1	pints	pt
L	liters	1.06	quarts	qt
L	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F